

TRACE METAL CAPTURE BY VARIOUS SORBENTS DURING FLUIDIZED BED COAL COMBUSTION

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INTRODUCTION

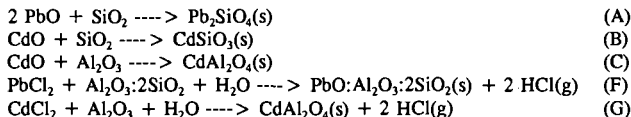
Toxic trace metallic elements such as arsenic, beryllium, cadmium, chromium, cobalt, lead, manganese, mercury, nickel, and selenium are usually contained in coal in various forms and trace amounts. These metals will either stay in the ash or be vaporized during high temperature combustion. Portions of the vaporized metals may eventually be emitted from a combustion system in the form of metal fumes or particulates with diameters less than 1 micron, which are potentially hazardous to the environment (1).

Current practice of controlling trace metal emissions during coal combustion employs conventional air pollution control devices (APCDs), such as electrostatic precipitators and baghouses, to collect fly ash and metal fumes. The control may not always be effective on metal fumes due to their extremely fine sizes (2).

This study is to explore the opportunities for improved control of toxic trace metal emissions from coal-fired combustion systems. Specifically, the technology proposed is to employ suitable sorbents to (1) reduce the amount of metal volatilization and (2) capture volatilized metal vapors during fluidized bed coal combustion. The objective of the study was to investigate experimentally and theoretically the metal capture process.

POTENTIAL METAL-SORBENT REACTIONS

The following reactions between metals and sorbent constituents have been confirmed both theoretically and experimentally (3,4,5):



EQUILIBRIUM CALCULATION

In this study, combustion equilibrium was calculated using a PC-based computer software package (6) especially developed for predicting equilibrium compositions during fuel or waste combustion. The simulation would reveal potential metal-sorbent reactions for the proposed metal capture process.

EXPERIMENTAL

Metal capture experiments were carried out semi-batchwise in a 25.4 mm (1") OD quartz fluidized bed coal combustor enclosed in an electric furnace. The metals involved in the study were cadmium, chromium and lead. Three coal samples from the Illinois Basin Coal Sample Bank (IBCSB) and an artificially prepared metal-containing wood sample were tested in the experiments. The corresponding concentration of chlorine, sulfur, and the target metals in each sample is summarized in Table 1. The sorbents tested included bauxite, zeolite and lime. The chemical composition and fluidization properties of the sorbents are listed in Table 2.

For an experimental run, a bed of sorbent was preheated to the desired temperature under the designed operating conditions. A predetermined amount of coal or wood pellets was then charged in the bed at a constant feed rate for combustion. After the combustion was completed, the bed residue was discharged for analysis of metal concentration. The experimental parameters and operating conditions associated with the experiments are shown in Table 3. Metal concentration in the coal, wood pellets, original sorbent, and combustor residue was determined by an atomic absorption spectrophotometer. An HF modified EPA Method 3050 was used to digest metals from the sorbent, which involves the use of HNO₃, HCl and HF acids (7).

RESULTS AND DISCUSSION

Simulation Results

Equilibrium calculations were performed to identify thermodynamically preferred metal speciation in a combustion system. A typical set of simulation results indicating potential lead-sorbent reactions and the effect of sulfur on lead capture by sorbents are shown in Table 4. The corresponding elemental composition and combustion conditions used in the simulations were: carbon - 71.3 wt%, hydrogen - 5.2 wt%, nitrogen - 1.4 wt%, oxygen - 12.4 to 7.8 wt%, sulfur - 0 to 4.6 wt%, lead concentration - 50 ppm, ash - 9.3 wt%, combustion temperature - 900°C, and percent excess air - 50%.

Experimental Results

Typical experimental results indicating the effectiveness of metal capture by various sorbents are shown in Tables 5, 6 and 7 for lead, cadmium, and chromium, respectively. The combustible materials tested were three coal samples, i.e., IBC-110, IBC-111 and IBC-112, and a wood sample. The sorbents used were bauxite, zeolite and lime. It is essential to point out that, due to the non-uniformity and trace-quantity nature associated with the process, it is still difficult to discuss the effect of fuel type, coal type, and coal properties such as chlorine, sulfur, ash and metal contents on the metal capture process based on the current results. Additional experiments are being carried out to provide more statistically representative results for better understanding the metal capture process.

CONCLUSIONS

This study investigated the possibility of employing suitable sorbents to capture toxic trace metals during fluidized bed coal combustion. The observed experimental results indicated that metal capture by sorbents can be as high as 91% depending on the metal species and sorbent involved. All three sorbents tested, i.e., bauxite, zeolite and lime, were observed to be capable of capturing lead and cadmium in a various degree. Zeolite and lime were able to capture chromium. Results from equilibrium simulations suggested the formation of metal-sorbent compounds such as $Pb_2SiO_4(s)$, $CdAl_2O_4(s)$ and $CdSiO_3(s)$ under the combustion conditions.

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Table 1. Concentration of Chlorine, Sulfur and Target Metals in Tested Coal Samples and Wood pellets (Units: ppm for metals, % for Cl and S)

Species	IBC-110	IBC-111	IBC-112	Wood*
Cd	<0.4	<0.4	<0.3	5
Cr	11	14	14	20
Pb	10	18	27	30
Cl	0.0%	0.0%	0.2%	0.0%
S	4.6%	2.0%	2.8%	0.0%

*Spiked Metals: Metal Nitrates

Table 2. Major Composition, Trace Metal Concentration and Fluidization Properties of the Three Tested Sorbents

Composition or Property	Bauxite	Zeolite	Lime
SiO ₂ (%)	9.0	66.7	0.7
Al ₂ O ₃ (%)	78.0	12.1	0.3
CaO (%)	0.0	3.1	97.2
Cd (ppm)	3.0	1.3	2.5
Cr (ppm)	286	3.5	4.5
Pb (ppm)	51.8	22.0	25.2
d _p (mm)	0.5	0.5	0.5
U _{mf} (cm/s)	3.8	3.5	3.8

Table 3. Experimental Parameters and Operating Conditions

Parameter	Range
Fuel Type	Coal, Wood
Coal Size	2.0 - 2.8 mm
Wood Size	4.8 mm
Fuel Amount	60 g
Fuel Feed Rate	0.22 g/min
Sorbent Type	Bauxite, Zeolite, Lime
Sorbent Size	0.4-0.6 mm
Sorbent Amount	22.5-30 g
Static Sorbent Height	6 cm
Air Flow Rate	3 U _{mf} of Sorbent
Combustor Temperature	900°C
Combustion Duration	4.5 hrs

Table 4. Equilibrium Simulation Results for Lead with or without Sulfur

Sorbent Constituent	Metal	With or Without Sulfur	Sulfur-Metal-Sorbent Compound
SiO ₂	Pb	Without S	Pb ₂ SiO ₄ (s) < 1000°C
			PbO(g) > 1000°C
		With S	PbSO ₄ (s) < 950°C
			Pb ₂ SiO ₄ (s) < 1000°C
			PbO(g) > 1000°C
Al ₂ O ₃	Pb	Without S	PbO(s) < 900°C
			PbO(g) > 900°C
		With S	PbSO ₄ (s) < 950°C
			PbO(g) > 950°C
CaO	Pb	Without S	PbO(s) < 900°C
			PbO(g) > 900°C
		With S	CaSO ₄ (s) > 500°C
			PbSO ₄ (s) < 950°C
			PbO(g) > 950°C

Table 5. Percentage Lead Capture by Sorbents (%)

Fuel Type	Bauxite	Zeolite	Lime
Coal (IBC-110)	68	60	27
Coal (IBC-111)	58	91	51
Coal (IBC-112)	66	51	21
Wood Pellets	48	52	53

Table 6. Percentage Cadmium Capture by Sorbents (%)

Fuel Type	Bauxite	Zeolite	Lime
Coal (IBC-110)	66	64	43
Coal (IBC-111)	74	21	57
Coal (IBC-112)	72	84	21
Wood Pellets	14	36	8

Table 7. Percentage Chromium Capture by Sorbents (%)

Fuel Type	Bauxite	Zeolite	Lime
Coal (IBC-110)	0	57	8
Coal (IBC-111)	0	19	5
Coal (IBC-112)	0	17	12
Wood Pellets	0	33	34